Fieldbus Foundation™

...dedicated to a single international fieldbus

Technical Overview

FOUNDATION™ fieldbus

Compliments of:

FD-043 Rev 2.0

Preface

FOUNDATION Fieldbus Technical Overview

FD-043 Revision 2.0

This technical overview booklet has been prepared to aid understanding of the technical aspects of FOUNDATION fieldbus.

The booklet begins with a brief overview of fieldbus benefits followed by the goals, principles and organization of the not-for-profit Fieldbus Foundation.

The main portion of the booklet is devoted to the definition and explanation of key technical concepts underpinning FOUNDATION fieldbus technology.

I sincerely hope this information proves useful to you. Please contact the Fieldbus Foundation if you need additional information about this exciting new technology.

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Introduction

1.0 WHAT IS FOUNDATION FIELDBUS?

FOUNDATION fieldbus is an all digital, serial, two-way communication system running at 31.25 kbit/s which interconnects “field” equipment such as sensors, actuators and controllers. Fieldbus is a Local Area Network (LAN) for instruments used in both process and manufacturing automation with built-in capability to distribute the control application across the network (Figure 1).

The fieldbus environment is the base level group of digital networks in the hierarchy of plant networks (Figure 2).

The fieldbus retains the desirable features of the 4-20 milliampere (mA) analog system such as:

- a standardized physical interface to the wire
- bus-powered devices on a single wire pair
- intrinsic safety options

In addition, FOUNDATION fieldbus enables:

- increased capabilities due to full digital communications
- reduced wiring and wire terminations due to multiple devices on one wire
- increased selection of suppliers due to interoperability
- reduced loading on control room equipment due to possible distribution of some control and input/output functions to field devices
- connection to a High Speed Ethernet backbone for larger systems

1.1 Fieldbus Benefits

Significant benefits are achieved in the control system life-cycle through the application of fieldbus technology (Figure 3).

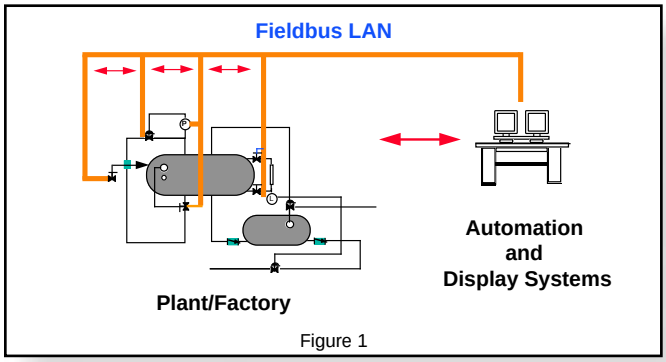

Figure 1

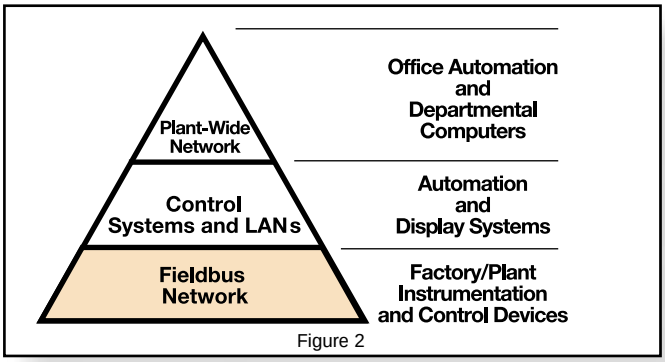

Figure 2

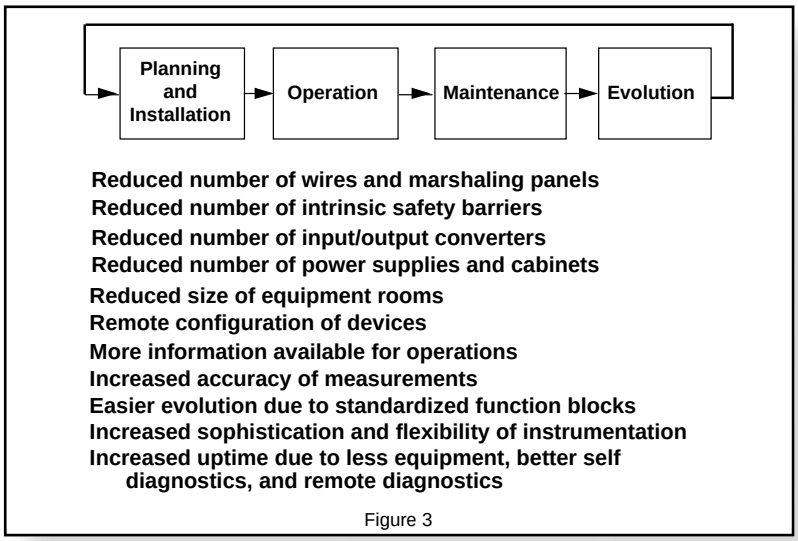

Figure 3

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1.1.1 More Data Available

The fieldbus allows multiple variables from each device to be brought into the control system for archival, trend analysis, process optimization studies, and report generation. The high resolution and distortion-free characteristics of digital communications enables improved control capability which can increase product yields (Figure 4).

1.1.2 Expanded View of the Process

The self-test and communication capabilities of microprocessor-based fieldbus devices helps reduce downtime and improve plant safety.

Upon detection of abnormal conditions or the need for preventive maintenance, plant operations and maintenance personnel can be notified. This allows corrective action to be initiated quickly and safely (Figure 5).

1.1.3 Reduction in System Hardware

FOUNDATION fieldbus uses standard "Function Blocks" to implement the control strategy. Function Blocks are standardized automation functions. Many control system functions such as analog input (AI), analog output (AO) and Proportional/Integral/Derivative (PID) control may be performed by the field device through the use of Function Blocks (Figure 6).

The consistent, block-oriented design of function blocks allows distribution of functions in field devices from different manufacturers in an integrated and seamless manner.

Distribution of control into the field devices can reduce the amount of I/O and control equipment needed including card files, cabinets, and power supplies.

1.1.4 Wiring Savings

The fieldbus allows many devices to connect to a single wire pair. This results in less wire, fewer intrinsic safety barriers, and fewer marshaling cabinets (Figure 7).

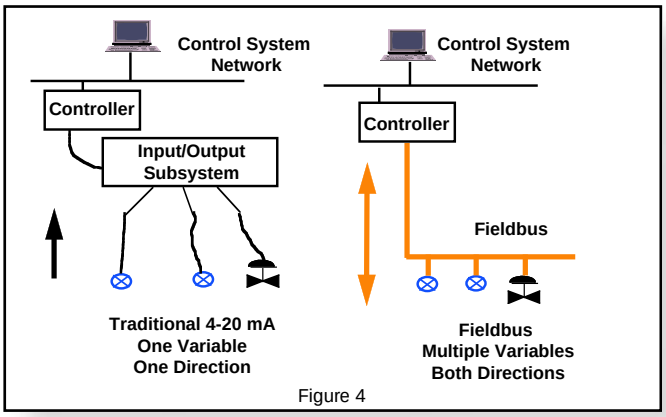

Figure 4

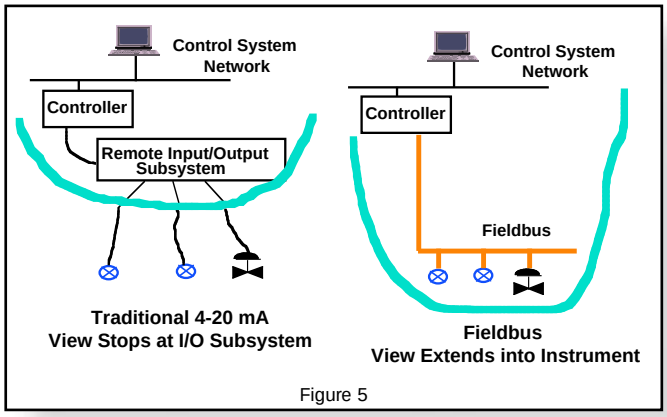

Figure 5

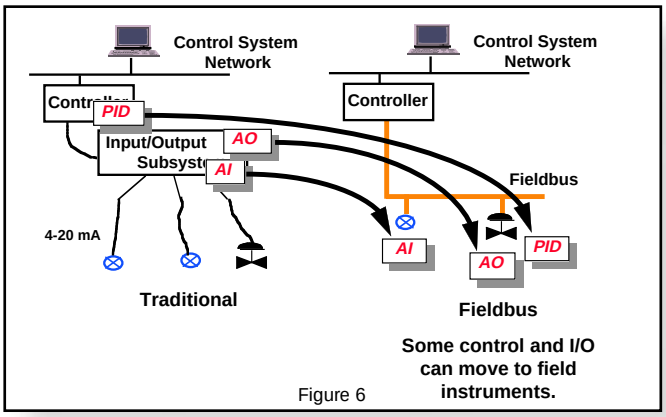

Figure 6

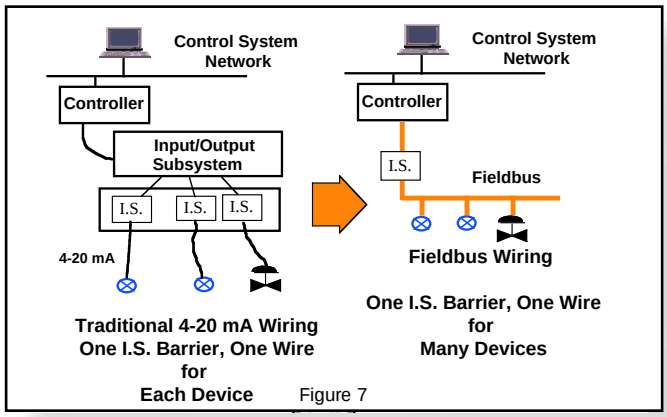

Figure 7

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2.0 WHAT IS THE FIELDBUS FOUNDATION?

Driven by their customers' needs, process control and manufacturing automation companies formed the Fieldbus Foundation to complete development of a single, open, international, and interoperable fieldbus.

The Fieldbus Foundation is an independent, not-for-profit organization based on the following principles:

- Fieldbus technology is an enabling technology; not a differentiating technology.
- Fieldbus technology is open and available to all parties.
- Fieldbus technology is based on the work of the International Electrotechnical Commission (IEC) and ISA (the international society for measurement and control).
- Fieldbus Foundation members support and work in the standards committees.

2.1 Organization

The Fieldbus Foundation is organized as in Figure 8.

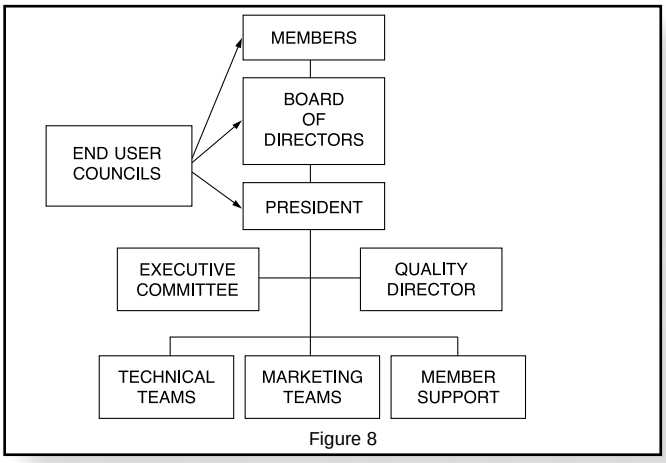

Figure 8

2.1.1 Members

The Fieldbus Foundation has over 130 member companies. These companies supply over 90% of the world's instrumentation and control products.

2.1.2 Board of Directors

The foundation is managed under the direction of the Board of Directors (BOD). The BOD is elected by the voting members.

2.1.3 President

The President reports to the Board of Directors, manages the day-to-day activities of the Fieldbus Foundation, and provides direction for the Executive, Technical, Marketing, and Member Support functions.

2.1.4 End User Councils

The End User Councils (EUC) are comprised of users of fieldbus equipment. There are EUCs in North America, Europe, Latin America and Asia-Pacific. The purpose of the EUC is to review the activities of the foundation and provide input to help ensure the specifications meet the needs of the marketplace.

2.1.5 Quality Director

The Quality Director provides overall management of the foundation's quality assurance systems.

2.1.6 Executive Committee

The Executive Committee advises the President concerning the strategic and overall operational issues of the foundation.

2.1.7 Technical Teams

The Technical Teams are responsible for the technical work of the foundation. The technical work is grouped into programs such as Specifications, Software, and Interoperability Testing. A Program Manager is responsible for each technical program.

2.1.8 Marketing Teams

The Marketing Teams are responsible for promoting FOUNDATION fieldbus and for planning and directing the foundation's products and services.

2.1.9 Member Support

Member Support is responsible for coordination and delivery of the Foundation's products and services. Products and services include technical consulting and training, newsletter printing and distribution, memberships, coordination of trade shows and field tests, product catalogs, Device Description software, and device registrations.

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3.0 FOUNDATION FIELDBUS TECHNOLOGY

FF-800 System Architecture Specification*

*Note: References to specific documents are noted as follows: Document number and name.

FOUNDATION fieldbus technology consists of: 1) the Physical Layer, 2) the Communication "Stack," and 3) the User Application. The Open Systems Interconnect (OSI) layered communication model is used to model these components (Figure 9).

The Physical Layer is OSI layer 1. The Data Link Layer (DLL) is OSI layer 2. The Fieldbus Message Specification (FMS) is OSI layer 7. The Communication Stack is comprised of layers 2 and 7 in the OSI model.

The fieldbus does not use OSI layers 3, 4, 5 and 6. The Fieldbus Access Sublayer (FAS) maps the FMS onto the DLL.

The User Application is not defined by the OSI model. The Fieldbus Foundation has specified a User Application model.

Each layer in the communication system is responsible for a portion of the message that is transmitted on the fieldbus.

The numbers below show the approximate number of eight bit "octets" used for each layer to transfer the USER data (Figure 10).

3.1 Physical Layer (31.25 kbit/s)

ISA S50.02-1992 ISA Physical Layer Standard
IEC 61158-2 (1993) International Physical Layer Standard
FF-816 31.25 kbit/s Physical Layer Profile Specification
FF-818 31.25 kbit/s Fiber Optic Physical Layer Profile

The Physical Layer is defined by approved standards from the International Electrotechnical Commission (IEC) and ISA (the international society for measurement and control).

The Physical Layer receives messages from the communication stack and converts the messages into physical signals on the fieldbus transmission medium and vice-versa.

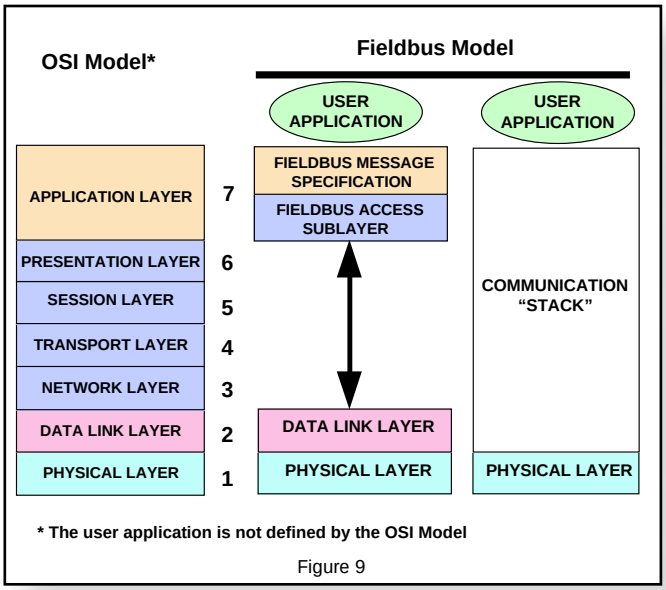

Figure 9

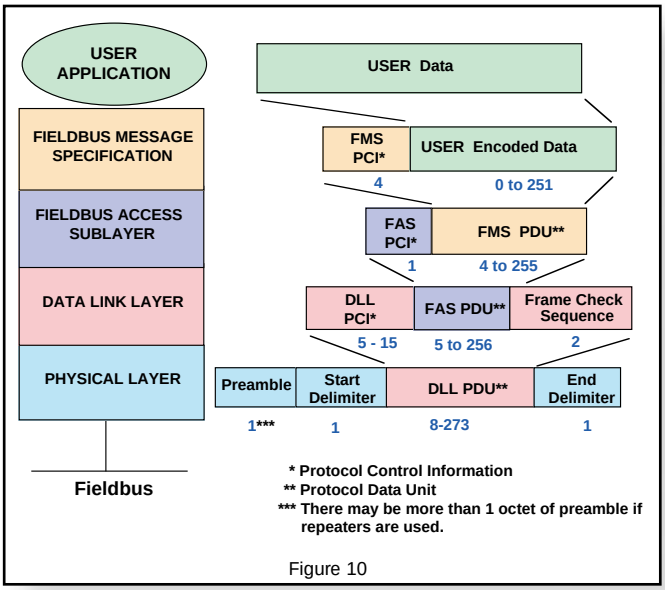

Figure 10

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Conversion tasks include adding and removing preambles, start delimiters, and end delimiters (Figure 11).

Fieldbus signals are encoded using the well-known Manchester Biphase-L technique. The signal is called “synchronous serial” because the clock information is embedded in the serial data stream. Data is combined with the clock signal to create the fieldbus signal as shown in the figure below. The receiver of the fieldbus signal interprets a positive transition in the middle of a bit time as a logical “0” and a negative transition as a logical “1” (Figure 12).

Special characters are defined for the preamble, start delimiter, and end delimiter (Figure 13).

The preamble is used by the receiver to synchronize its internal clock with the incoming fieldbus signal.

Special N+ and N- codes are in the start delimiter and end delimiter. Note that the N+ and N- signals do not transition in the middle of a bit time. The receiver uses the start delimiter to find the beginning of a fieldbus message. After it finds the start delimiter, the receiver accepts data until the end delimiter is received.

3.1.1 31.25 kbit/s Fieldbus Signaling

The transmitting device delivers ± 10 mA at 31.25 kbit/s into a 50 ohm equivalent load to create a 1.0 volt peak-to-peak voltage modulated on top of the direct current (DC) supply voltage.

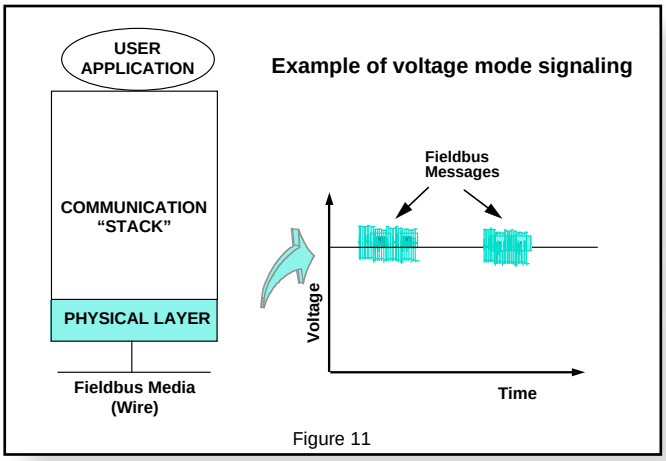

Figure 11

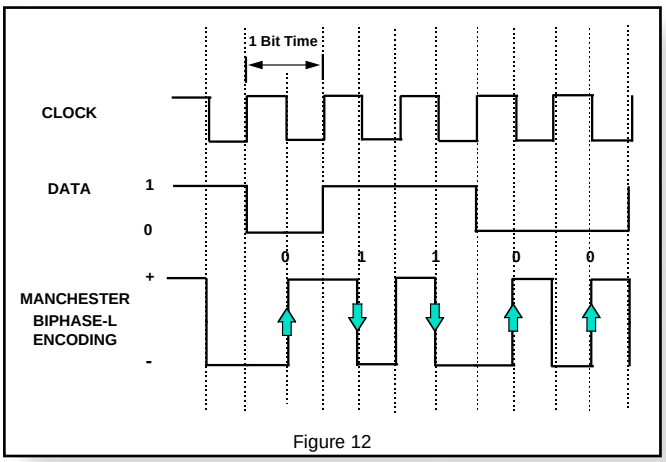

Figure 12

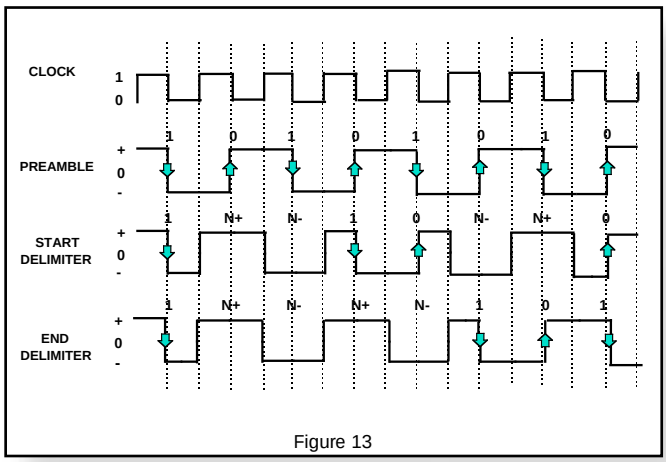

Figure 13

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The DC supply voltage can range from 9 to 32 volts. However, for I.S. applications, the allowed power supply voltage depends on the barrier rating (Figure 14).

31.25 kbit/s devices can be powered directly from the fieldbus and operate on wiring previously used for 4-20 mA devices.

The 31.25 kbit/s fieldbus also supports intrinsically safe (I.S.) fieldbuses with bus powered devices. To accomplish this, an I.S. barrier is placed between the power supply in the safe area and the I.S. device in the hazardous area.

3.1.2 31.25 kbit/s Fieldbus Wiring

AG-140 31.25 kbit/s Wiring and Installation Guide
AG-163 31.25 kbit/s Intrinsically Safe Systems Application Guide
AG-165 Fieldbus Installation and Planning Guide

The 31.25 kbit/s fieldbus allows stubs or “spurs” (Figure 15).

The length of the fieldbus is determined by the communication rate, cable type, wire size, bus power option, and I.S. option.

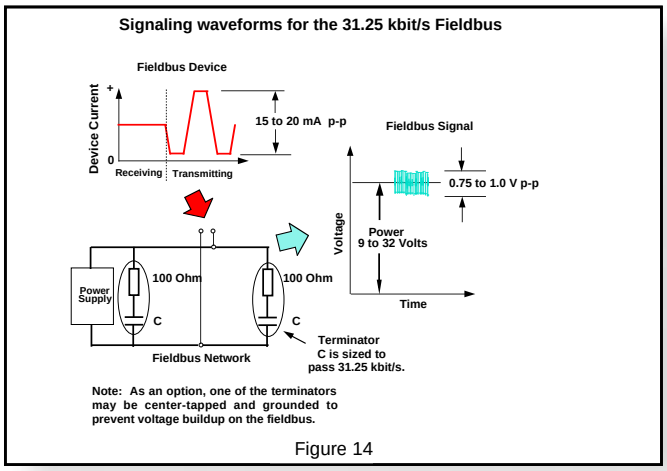

Figure 14

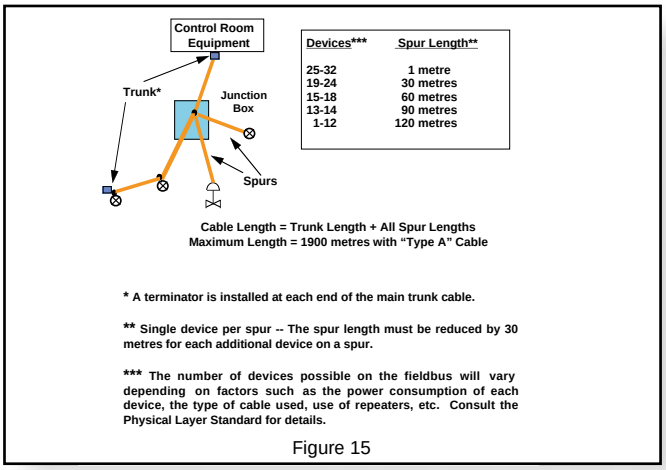

Figure 15

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Figure 16 gives a summary of examples of options available in the Physical Layer standard.

3.2 Communication Stack

The following sections will describe the operation of the layers in the Communication Stack (Figure 17).

3.2.1 The Data Link Layer (DLL)

FF-821 Data Link Layer Services Subset Specification

FF-822 Data Link Layer Protocol Subset Specification

Layer 2, the Data Link Layer (DLL), controls transmission of messages onto the fieldbus. The DLL manages access to the fieldbus through a deterministic centralized bus scheduler called the Link Active Scheduler (LAS).

The DLL is a subset of the emerging IEC/ISA DLL standard.

Characteristics	Data Rate		
	31.25 kbit/s	31.25 kbit/s	31.25 kbit/s
Type	Voltage	Voltage	Voltage
Topology	Bus/tree	Bus/tree	Bus/tree
Bus Power	none	DC	DC
Classification		Intrinsically Safe	
Number of Devices*	2-32	2-6	2-12
Cable Length	1900 m	1900 m	1900 m
Spur Length	120 m	120 m	120 m

Figure 16

* The number of devices possible on a fieldbus link depends on factors such as the power consumption of each device, the type of cable used, use of repeaters, etc. Consult the Physical Layer Standard for details. The number of network addresses available for each link is 240.

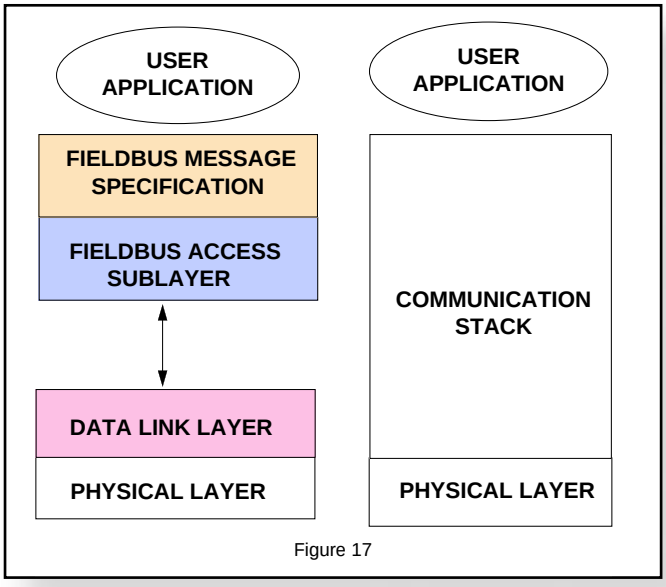

Figure 17

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3.2.1.1 Device Types

Two types of devices are defined in the DLL specification:

- Basic Device
- Link Master

Link Master devices are capable of becoming the Link Active Scheduler (LAS). **Basic** devices do not have the capability to become the LAS (Figure 18).

3.2.1.2 Scheduled Communication

The Link Active Scheduler (LAS) has a list of transmit times for all data buffers in all devices that need to be cyclically transmitted.

When it is time for a device to send a buffer, the LAS issues a Compel Data (CD) message to the device.

Upon receipt of the CD, the device broadcasts or "publishes" the data in the buffer to all devices on the fieldbus. Any device configured to receive the data is called a "subscriber" (Figure 19).

Scheduled data transfers are typically used for the regular, cyclic transfer of control loop data between devices on the fieldbus.

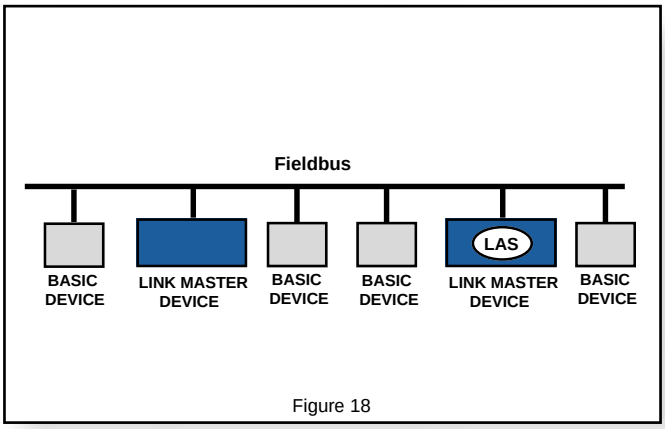

Figure 18

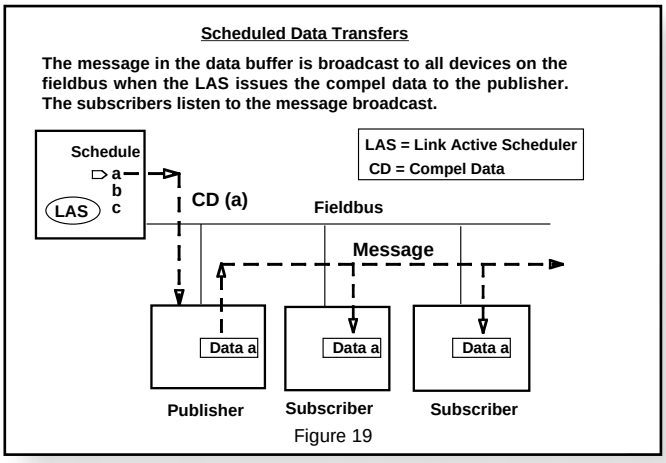

Figure 19

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3.2.1.3 Unscheduled Communication

All of the devices on the fieldbus are given a chance to send “unscheduled” messages between transmissions of scheduled messages.

The LAS grants permission to a device to use the fieldbus by issuing a pass token (PT) message to the device. When the device receives the PT, it is allowed to send messages until it has finished or until the “maximum token hold time” has expired, whichever is the shorter time (Figure 20).

3.2.1.4 Link Active Scheduler Operation

The following sections describe the overall operation of the Link Active Scheduler (LAS). The algorithm used by the LAS is shown in Figure 21.

3.2.1.4.1 CD Schedule

The CD Schedule contains a list of activities that are scheduled to occur on a cyclic basis. At precisely the scheduled time, the LAS sends a Compel Data (CD) message to a specific data buffer in a fieldbus device. The device immediately broadcasts or “publishes” a message to all devices on the fieldbus. This is the highest priority activity performed by the LAS. The remaining operations are performed between scheduled transfers.

3.2.1.4.2 Live List Maintenance

The list of all devices that are properly responding to the Pass Token (PT) is called the “Live List.”

New devices may be added to the fieldbus at any time. The LAS periodically sends Probe Node (PN) messages to the addresses not in the Live List. If a device is present at the address and receives the PN, it immediately returns a Probe Response (PR) message. If the device answers with a PR, the LAS adds the device to the Live List and confirms its addition by sending the device a Node Activation message.

The LAS is required to probe at least one address after it has completed a cycle of sending PTs to all devices in the Live List.

The device will remain in the Live List as long as it responds properly to the PTs sent from the LAS. The LAS will remove a device from the Live List if the device does not either use the token or immediately return it to the LAS after three successive tries.

Whenever a device is added or removed from the Live List, the LAS broadcasts changes to the Live List to all devices. This allows each device to maintain a current copy of the Live List.

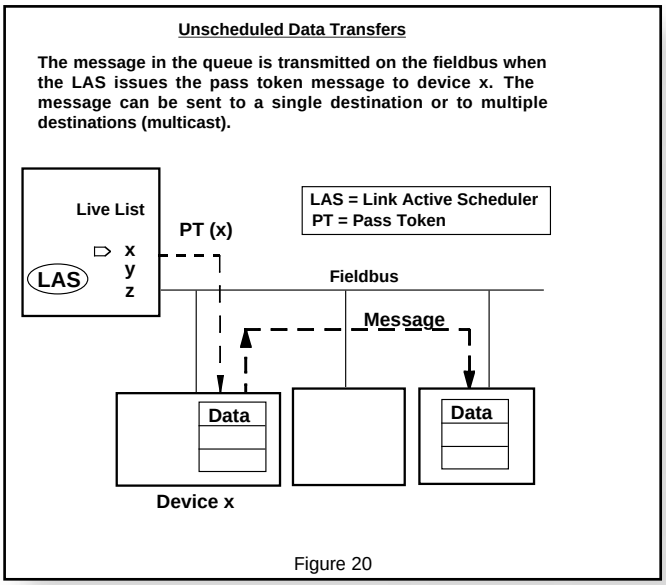

Figure 20

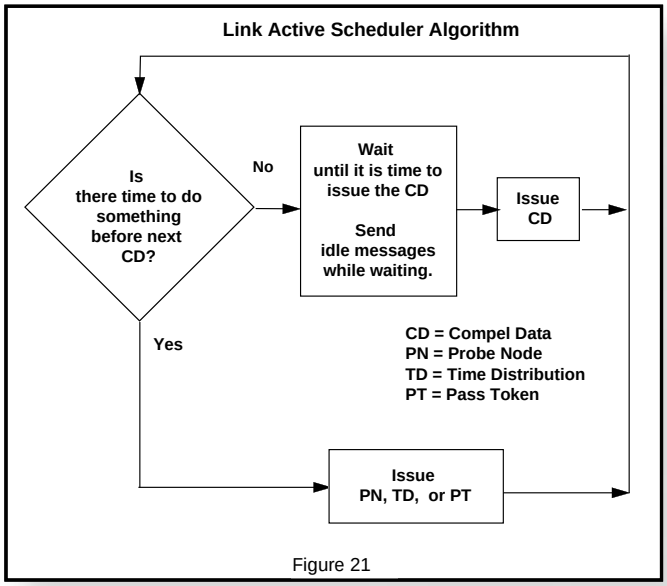

Figure 21

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3.2.1.4.3 Data Link Time Synchronization

The LAS periodically broadcasts a Time Distribution (TD) message on the fieldbus so that all devices have exactly the same data link time. This is important because scheduled communications on the fieldbus and scheduled function block executions in the User Application are based on information obtained from these messages.

3.2.1.4.4 Token Passing

The LAS sends a Pass Token (PT) message to all devices in the Live List. The device is allowed to transmit unscheduled messages when it receives the PT.

3.2.1.4.5 LAS Redundancy

A fieldbus may have multiple Link Masters. If the current LAS fails, one of the Link Masters will become the LAS and the operation of the fieldbus will continue. The fieldbus is designed to "fail operational."

3.2.2 Fieldbus Access Sublayer (FAS)

FF-875 Fieldbus Access Sublayer Specification

The FAS uses the scheduled and unscheduled features of the Data Link Layer to provide a service for the Fieldbus Message Specification (FMS). The types of FAS services are described by Virtual Communication Relationships (VCR).

The VCR is like the speed dial feature on your memory telephone. There are many digits to dial for an international call such as international access code, country code, city code, exchange code and finally the specific telephone number.

This information only needs to be entered once and then a "speed dial number" is assigned.

After setup, only the speed dial number needs to be entered for the dialing to occur. Likewise, after configuration, only the VCR number is needed to communicate with another fieldbus device.

Just as there are different types of telephone calls such as person to person, collect, or conference calls, there are different types of VCRs.

3.2.2.1 Client/Server VCR Type

The Client/Server VCR Type is used for queued, unscheduled, user initiated, one to one, communication between devices on the fieldbus.

Queued means that messages are sent and received in the order submitted for transmission, according to their priority, without overwriting previous messages.

When a device receives a Pass Token (PT) from the LAS, it may send a request message to another device on the fieldbus. The requester is called the "Client" and the device that received the request is called the "Server." The Server sends the response when it receives a PT from the LAS.

The Client/Server VCR Type is used for operator initiated requests such as setpoint changes, tuning parameter access and change, alarm acknowledge, and device upload and download.

3.2.2.2 Report Distribution VCR Type

The Report Distribution VCR Type is used for queued, unscheduled, user initiated, one to many communications.

When a device with an event or a trend report receives a Pass Token (PT) from the LAS, it sends its message to a "group address" defined for its VCR. Devices that are configured to listen on that VCR will receive the report.

The Report Distribution VCR Type is typically used by fieldbus devices to send alarm notifications to the operator consoles.

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3.2.2.3 Publisher/Subscriber VCR Type

The Publisher/Subscriber VCR Type is used for buffered, one to many communications.

Buffered means that only the latest version of the data is maintained within the network. New data completely overwrites previous data.

When a device receives the Compel Data (CD), the device will "Publish" or broadcast its message to all devices on the fieldbus. Devices that wish to receive the Published message are called "Subscribers."

The CD may be scheduled in the LAS, or it may be sent by Subscribers on an unscheduled basis. An attribute of the VCR indicates which method is used.

The Publisher/Subscriber VCR Type is used by the field devices for cyclic, scheduled, publishing of User Application function block input and outputs such as process variable (PV) and primary output (OUT) on the fieldbus.

3.2.2.4 Summary of VCR Types

(Figure 22).

3.2.3 Fieldbus Message Specification (FMS)

FF-870 Fieldbus Message Specification

Fieldbus Message Specification (FMS) services allow user applications to send messages to each other across the fieldbus using a standard set of message formats.

FMS describes the communication services, message formats, and protocol behavior needed to build messages for the User Application (Figure 23).

Data that is communicated over the fieldbus is described by an "object description." Object descriptions are collected together in a structure called an "object dictionary" (OD), (Figure 24).

The object description is identified by its "index" in the OD. Index 0, called the object dictionary header, provides a description of the dictionary itself, and defines the first index for the object descriptions of the User Application. The User Application object descriptions can start at any index above 255.

Index 255 and below define standard data types such as boolean, integer, float, bitstring, and data structures that are used to build all other object descriptions.

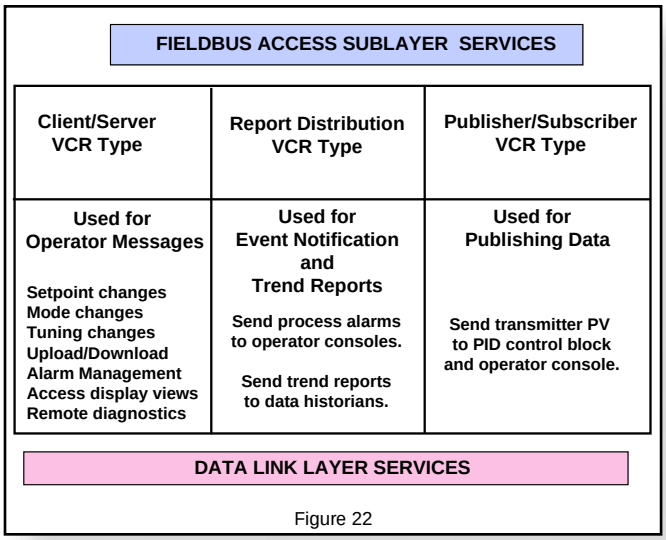

Figure 22

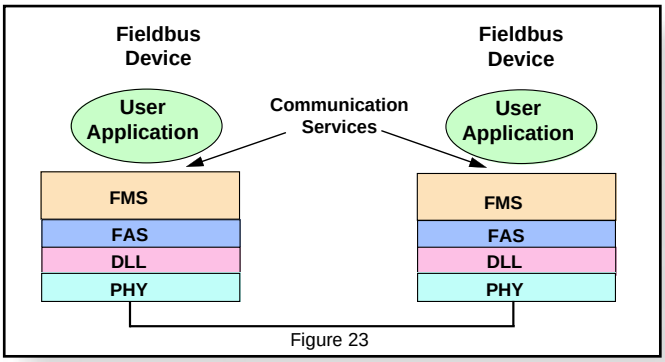

Figure 23

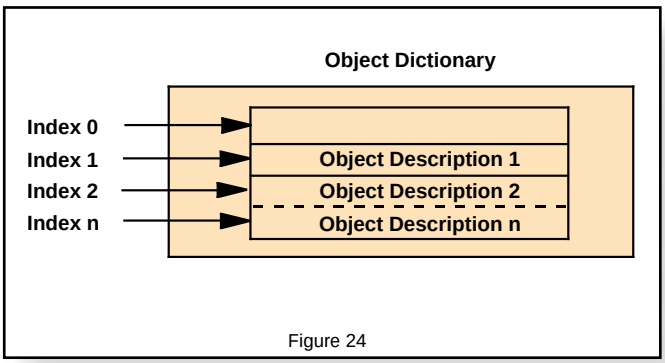

Figure 24

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3.2.3.1 Virtual Field Device (VFD)

A “Virtual Field Device” (VFD) is used to remotely view local device data described in the object dictionary. A typical device will have at least two VFDs (Figure 25).

Network Management (see FF-801 Network Management Specification) is part of the Network and System Management Application. It provides for the configuration of the communication stack. The Virtual Field Device (VFD) used for Network Management is also used for System Management. This VFD provides access to the Network Management Information Base (NMIB) and to the System Management Information Base (SMIB). NMIB data includes Virtual Communication Relationships (VCR), dynamic variables, statistics, and Link Active Scheduler (LAS) schedules (if the device is a Link Master). SMIB data includes device tag and address information, and schedules for function block execution.

System Management is described further in the User Application section.

3.2.3.2 Communication Services

FMS communication services provide a standardized way for user applications such as function blocks to communicate over the fieldbus. Specific FMS communication services are defined for each object type.

All of the FMS services can only use the Client/Server VCR Type except as noted.

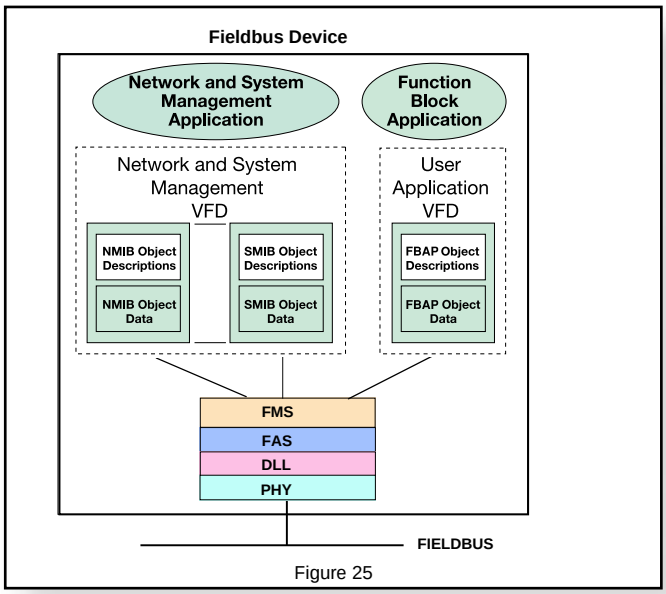

Figure 25

Detailed descriptions for each service are provided in the FF-870 Fieldbus Message Specification.

3.2.3.2.1 Context Management Services

The following FMS services are used to establish and release Virtual Communications Relationships (VCR) with, and determine the status of a VFD.

Initiate	Establish communications
Abort	Release communications
Reject	Reject improper service
Status	Read a device status
UnsolicitedStatus	Send unsolicited status
Identify	Read vendor, type and version

3.2.3.2.2 Object Dictionary Services

The following FMS services allow the User Application to access and change the object descriptions (OD) in a VFD.

GetOD	Read an object dictionary(OD)
InitiatePutOD	Start an OD Load
PutOD	Load an OD into a device
TerminatePutOD	Stop an OD Load

3.2.3.2.3 Variable Access Services

The following FMS services allow the user application to access and change variables associated with an object description.

Read	Read a variable
Write	Write a variable
InformationReport	Send Data*
DefineVariableList	Define a Variable List
DeleteVariableList	Delete a Variable List

Can use **Publisher/Subscriber or **Report Distribution** VCR Types.*

3.2.3.2.4 Event Services

The following FMS services allow the user application to report events and manage event processing.

EventNotification	Report an event*
AcknowledgeEventNotification	Acknowledge an event
AlterEventConditionMonitoring	Disable / Enable event *

** Can use **Report Distribution** VCR Type*

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3.2.3.2.5 Upload/Download Services

It is often necessary to remotely upload or download data and programs over the fieldbus, especially for more complex devices such as programmable logic controllers.

To allow uploads and downloads using the FMS services, a “Domain” is used. A Domain represents a memory space in a device.

The following FMS services allow the User Application to upload and download a Domain in a remote device.

RequestDomainUpload	Request Upload
InitiateUploadSequence	Open Upload
UploadSegment	Read data from device
TerminateUploadSequence	Stop Upload
RequestDomainDownload	Request Download
InitiateDownloadSequence	Open Download
DownloadSegment	Send data to device
TerminateDownloadSequence	Stop Download

3.2.3.2.6 Program Invocation Services

The “Program Invocation” (PI) allows the execution of a program in one device to be controlled remotely.

A device could download a program into a Domain (see previous section) of another device using the download service and then remotely operate the program by issuing PI service requests.

The state diagram for the PI is shown as an example of FMS protocol behavior later in this document.

CreateProgramInvocation	Create a program object
DeleteProgramInvocation	Delete a program object
Start	Start a program
Stop	Stop a program
Resume	Resume program execution
Reset	Reset the program
Kill	Remove the program

3.2.3.3 Message Formatting

ASN.1 Tutorial and Reference -- Steedman

The exact formatting of FMS messages is defined by a formal syntax description language called Abstract Syntax Notation 1 (ASN.1).

ASN.1 was developed by the International Telegraph and Telephone Consultative Committee (CCITT) in the early 1980s as a part of the CCITT mail standardization activities.

See Figure 26 for a partial example of ASN.1 definition for the FMS Read service.

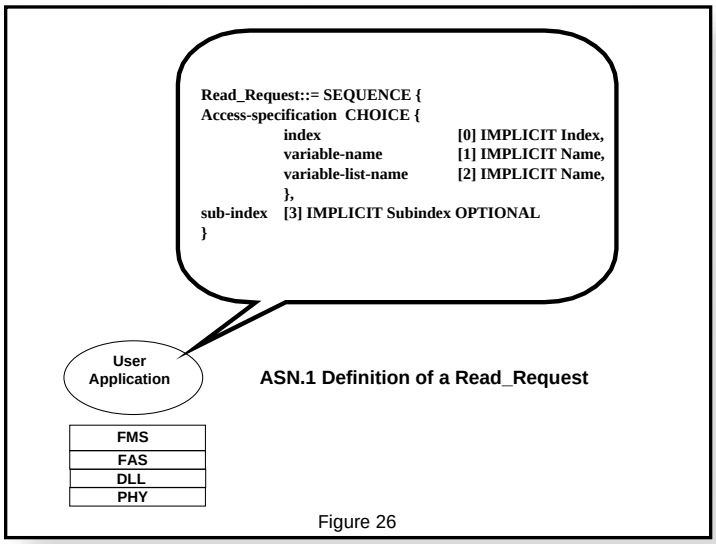

Figure 26

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This example states that the items Access-specification and sub-index occur in SEQUENCE in the message.

The Access-specification is a CHOICE of using either an index or a name to access a variable.

The sub-index is OPTIONAL. It is used only to select an individual element of an array or record variable.

The numbers in the brackets are the actual encoding numbers that are used to identify the fields in an encoded message.

3.2.3.4 Protocol Behavior

Certain types of objects have special behavioral rules that are described by the FMS specification. For example, the simplified behavior of a Program Invocation object is shown in Figure 27.

A remote device can control the state of the program in another device on the fieldbus. For example, the remote device would use the **Create Program Invocation** FMS service to change the program state from Non-existent to Idle.

The **Start** FMS service would be used to change the state from Idle to Running and so on.

3.3 User Application -- Blocks

FF-890 Function Blocks -- Part 1

The Fieldbus Foundation has defined a standard User Application based on “Blocks.” Blocks are representations of different types of application functions (Figure 28).

The types of blocks used in a User Application are described in Figure 29.

3.3.1 Resource Block

The Resource Block describes characteristics of the fieldbus device such as the device name, manufacturer, and serial number. There is only one resource block in a device.

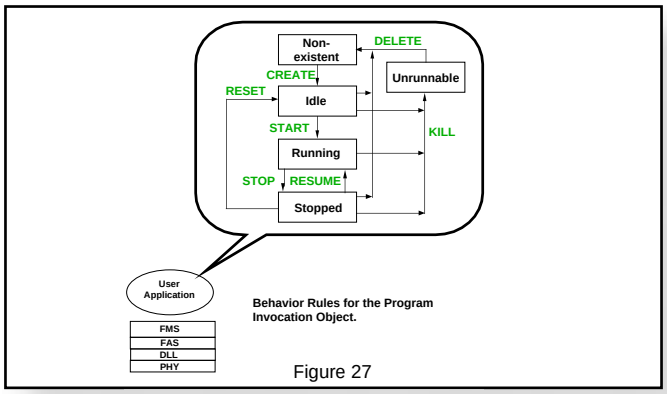

Figure 27

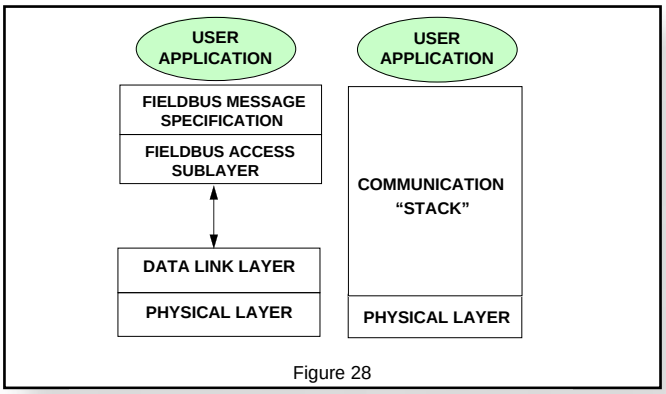

Figure 28

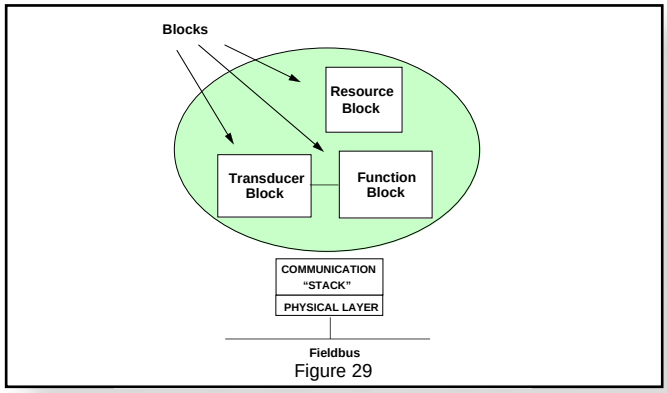

Figure 29

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3.3.2 Function Block

Function Blocks (FB) provide the control system behavior. The input and output parameters of Function Blocks can be linked over the fieldbus. The execution of each Function Block is precisely scheduled. There can be many function blocks in a single User Application.

The Fieldbus Foundation has defined sets of standard Function Blocks. Ten standard Function Blocks for basic control are defined by the FF-891 Function Blocks -- Part 2 specification. These blocks are listed below.

Function Block Name	Symbol
Analog Input	AI
Analog Output	AO
Bias	B
Control Selector	CS
Discrete Input	DI
Discrete Output	DO
Manual Loader	ML
Proportional/Derivative	PD
Proportional/Integral/Derivative	PID
Ratio	RA

Nineteen additional standard Function Blocks for advanced control are defined in the FF-892 Function Blocks -- Part 3 specification.

Function blocks can be built into fieldbus devices as needed to achieve the desired device functionality. For example, a simple temperature transmitter may contain an AI function block. A control valve might contain a PID function block as well as the expected AO block.

Thus a complete control loop can be built using only a simple transmitter and a control valve (Figure 30).

3.3.3 Transducer Blocks

Transducer Blocks decouple Function Blocks from the local input/output functions required to read sensors and command output hardware. They contain information such as calibration date and sensor type. There is usually one transducer block for each input or output function block.

The following additional objects are defined in the User Application:

Link Objects define the links between Function Block inputs and outputs internal to the device and across the fieldbus network.

Trend Objects allow local trending of function block parameters for access by hosts or other devices.

Alert Objects allow reporting of alarms and events on the fieldbus.

View Objects are predefined groupings of block parameter sets that can be used by the human/machine interface. The function block specification defines four views for each type of block.

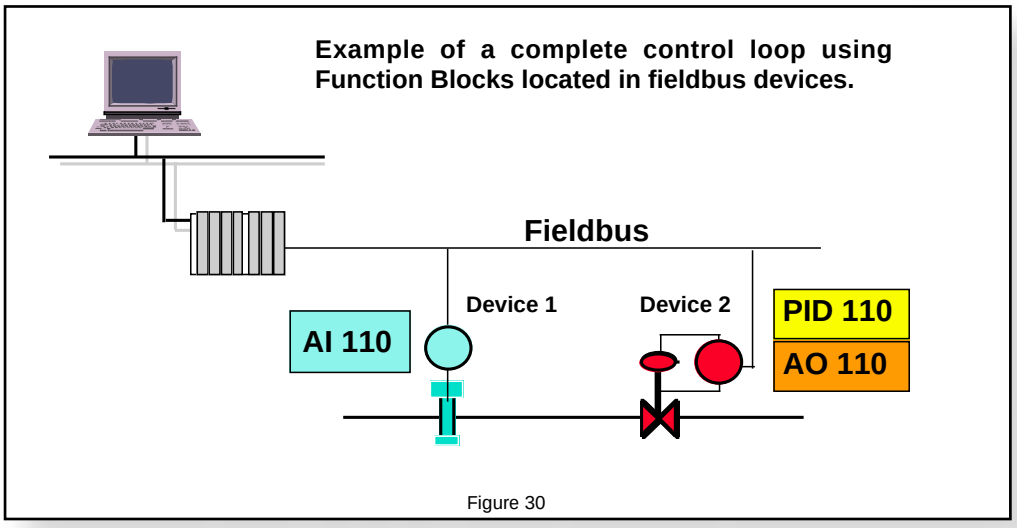

Figure 30

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Figure 31 shows an example of how common Function Block variables map into the views. Only a partial listing of the block parameters is shown in the example.

• VIEW_1 - Operation Dynamic - Information required by a plant operator to run the process.

• VIEW_2 - Operation Static - Information which may need to be read once and then displayed along with the dynamic data.

• VIEW_3 - All Dynamic - Information which is changing and may need to be referenced in a detailed display.

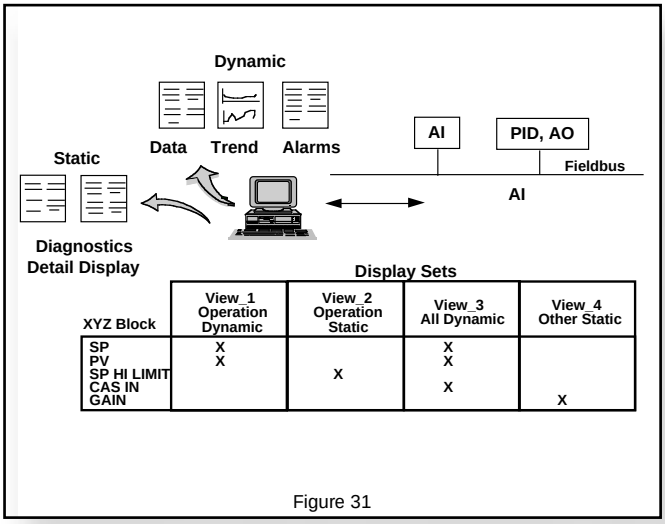
• VIEW_4 - Other Static - Configuration and maintenance information.

3.3.4 Fieldbus Device Definition

The function of a fieldbus device is determined by the arrangement and interconnection of blocks (Figure 32).

The device functions are made visible to the fieldbus communication system through the User Application Virtual Field Device (VFD) discussed earlier.

The header of the User Application object dictionary points to a Directory which is always the first entry in the function block application. The Directory provides the starting indexes of all of the other entries used in the Function Block application (Figure 33).



XYZ Block	View_1 Operation Dynamic	View_2 Operation Static	View_3 All Dynamic	View_4 Other Static
SP	X		X	
PV	X		X	
SP HI LIMIT		X		
CAS IN			X	
GAIN				X

Figure 31

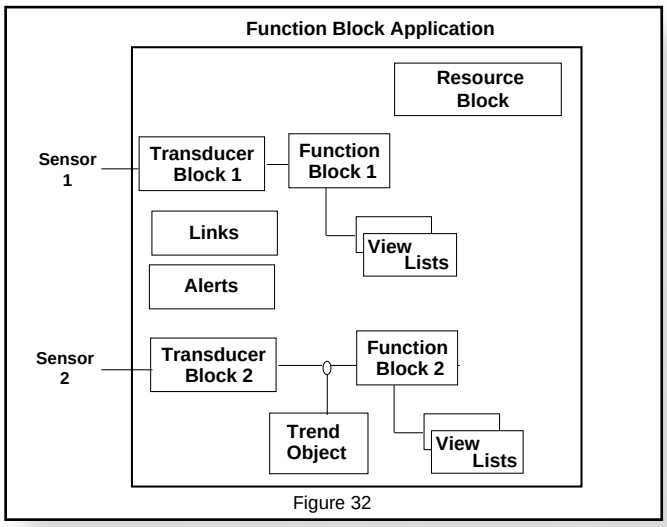


Figure 32

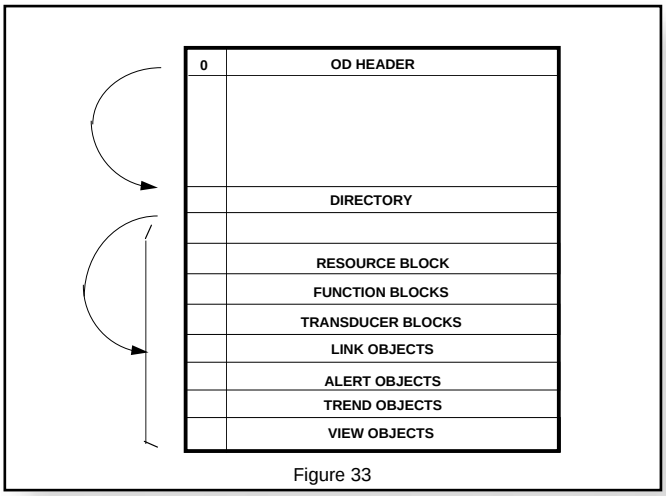


Figure 33

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The VFD object descriptions and their associated data are accessed remotely over the fieldbus network using Virtual Communication Relationships (VCRs) as shown below (Figure 34).

3.4 System Management

FF-800 System Management Specification

Function Blocks must execute at precisely defined intervals and in the proper sequence for correct control system operation.

System management synchronizes execution of the Function Blocks and the communication of function block parameters on the fieldbus.

System management also handles other important system features such as publication of the time of day to all devices, including automatic switchover to a redundant time publisher, automatic assignment of device addresses, and searching for parameter names or “tags” on the fieldbus.

All of the configuration information needed by System Management such as the Function Block schedule is described by object descriptions in the Network and System Management Virtual Field Device (VFD) in each device. This VFD provides access to the System Management Information Base (SMIB), and also to the Network Management Information Base (NMIB).

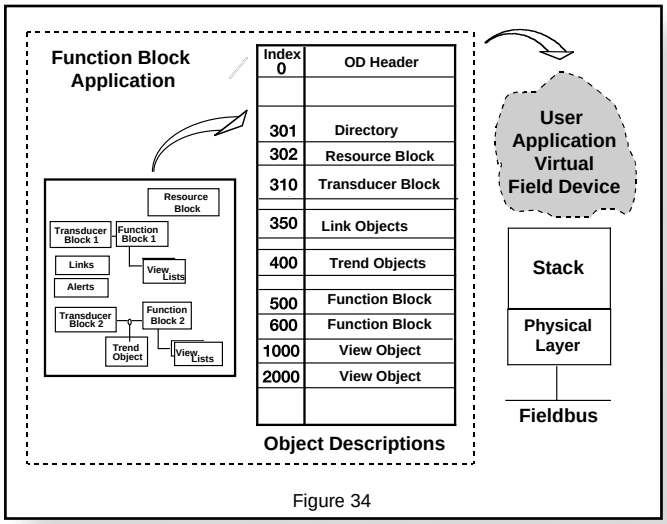

Figure 34

3.4.1 Function Block Scheduling

A schedule building tool is used to generate function block and Link Active Scheduler (LAS) schedules. Assume that the schedule building tool has built the following schedules for the loop previously described in Figure 30.

The schedules contain the start time offset from the beginning of the “absolute link schedule start time.” The absolute link schedule start time is known by all devices on the fieldbus (Figure 35).

A “macrocycle” is a single iteration of a schedule within a device. The following figure shows the relationships between the absolute link schedule start time, LAS macrocycle, device macrocycles, and the start time offsets.

	Offset from Absolute Link Schedule Start Time
Scheduled AI Function Block Extension	0
Scheduled Communications of AI	20
Scheduled PID Function Block Execution	30
Scheduled AO Function Block Execution	50

Figure 35

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In Figure 36, System Management in the transmitter will cause the AI function block to execute at offset 0. At offset 20 the Link Active Scheduler (LAS) will issue a Compel Data (CD) to the AI function block buffer in the transmitter and data in the buffer will be published on the fieldbus.

At offset 30 System Management in the valve will cause the PID function block to execute followed by execution of the AO function block at offset 50.

The pattern exactly repeats itself assuring the integrity of the control loop dynamics.

Note that during the function block execution, the LAS is sending the Pass Token message to all devices so that they can transmit their unscheduled messages such as alarm notifications or operator setpoint changes.

For this example, the only time that the fieldbus can not be used for unscheduled messages is from offset 20 to offset 30 when the AI function block data is being published on the fieldbus.

3.4.1.1 Application Clock Distribution

The FOUNDATION Fieldbus supports an application clock distribution function. The application clock is usually set equal to the local time of day or to Universal Coordinated Time.

System Management has a time publisher which periodically sends an application clock synchronization message to all fieldbus devices. The data link scheduling time is sampled and sent with the application clock message so that the receiving devices can adjust their local application time. Between synchronization messages, application clock time is independently maintained in each device based on its own internal clock.

Application Clock synchronization allows the devices to time stamp data throughout the fieldbus network. If there are backup application clock publishers on the fieldbus, a backup publisher will become active if the currently active time publisher should fail.

3.4.1.2 Device Address Assignment

Every fieldbus device must have a unique network address and physical device tag for the fieldbus to operate properly.

To avoid the need for address switches on the instruments, assignment of network addresses can be performed automatically by System Management.

The sequence for assigning a network address to a new device is as follows:

- A physical device tag is assigned to a new device via a configuration device. This can be done “off-line” at a bench or “on-line” through special default network addresses on the fieldbus.

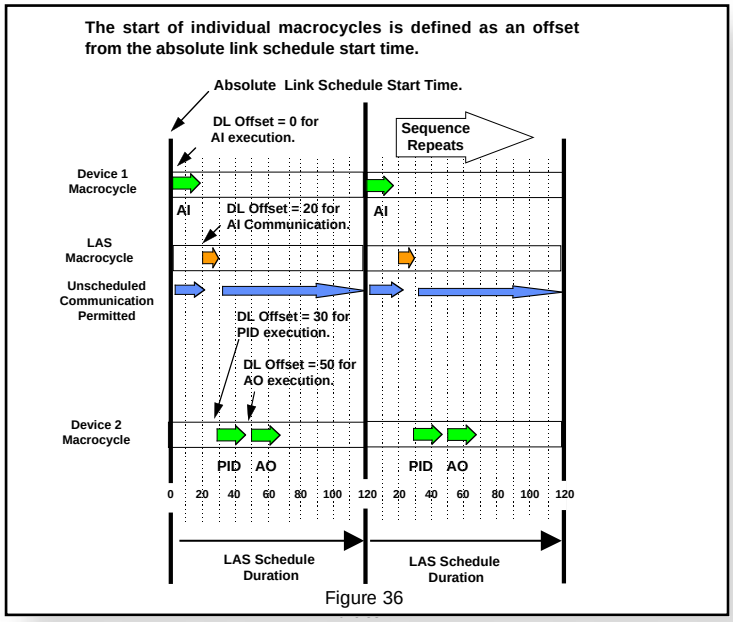

Figure 36

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- Using default network addresses, System Management asks the device for its physical device tag. System Management uses the physical device tag to look up the new network address in a configuration table. System Management then sends a special “set address” message to the device which forces the device to move to the new network address.

- The sequence is repeated for all devices that enter the network at a default address.

3.4.1.3 Find Tag Service

For the convenience of host systems and portable maintenance devices, System Management supports a service for finding devices or variables by a tag search.

The “find tag query” message is broadcast to all fieldbus devices. Upon receipt of the message, each device searches its Virtual Field Devices (VFD) for the requested tag and returns complete path information (if the tag is found) including the network address, VFD number, virtual communication relationship (VCR) index, and object dictionary (OD) index. Once the path is known, the host or maintenance device can access the data for the tag.

3.5 Device Descriptions

A critical characteristic required of fieldbus devices is interoperability. To achieve interoperability, Device Description (DD) technology is used in addition to standard function block parameter and behavior definitions.

The DD provides an extended description of each object in the Virtual Field Device (VFD) as shown in Figure 37.

The DD provides information needed for a control system or host to understand the meaning of the data in the VFD including the human interface for functions such as calibration and diagnostics. Thus the DD can be thought of as a “driver” for the device.

The DDs are similar to the drivers that your personal computer (PC) uses to operate different printers and other devices that are connected to the PC. Any control system or host can operate with the device if it has the device's DD.

3.5.1 Device Description Tokenizer

FD-900 Device Description Language Specification

FD-100 DDL Tokenizer User’s Manual

The DD is written in a standardized programming language known as Device Description Language (DDL). A PC-based tool called the “Tokenizer” converts DD source input files into DD output files by replacing key words and standard strings in the source file with fixed “tokens” as shown in Figure 38.

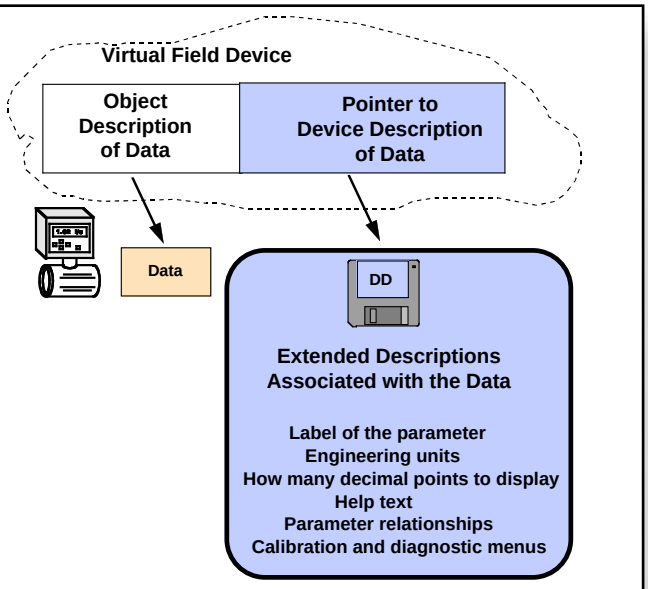

Figure 37

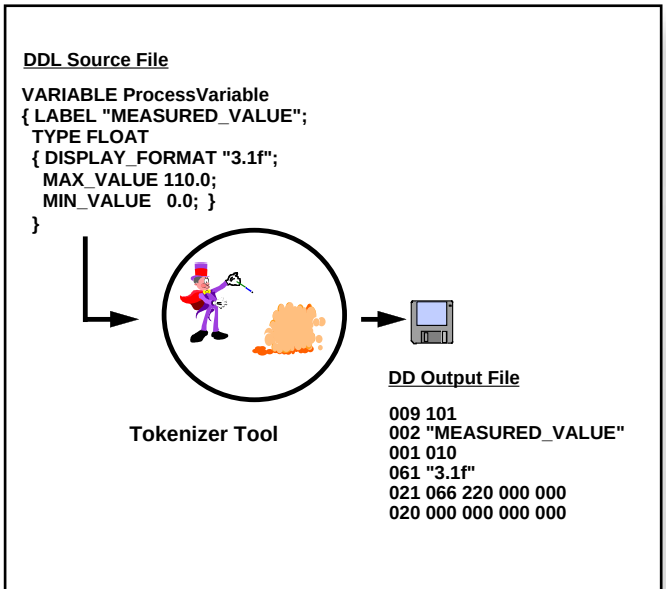

Figure 38

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The Fieldbus Foundation (FF) provides DDs for all standard Function Blocks and Transducer Blocks. Device suppliers will typically prepare an “incremental” DD which references the Standard DDs. Suppliers may also add supplier specific features such as calibration and diagnostic procedures to their devices. These features can also be described in the incremental DD.

The Fieldbus Foundation makes the Standard DDs available on a CD-ROM. The user can obtain the incremental DD from the device supplier or from the Fieldbus Foundation if the supplier has registered their incremental DD with the Fieldbus Foundation (Figure 39).

The incremental DDs can also be read directly from the device over the fieldbus, if the device supports the upload services and contains a Virtual Field Device (VFD) for the DD.

3.5.2 Device Description Services (DDS)

FD-110 DDS User’s Guide

On the host side, library functions called Device Description Services (DDS) are used to read the device descriptions (Figure 40).

Note that DDS reads descriptions, not operational values. The operational values are read from the fieldbus device over the fieldbus using FMS communication services.

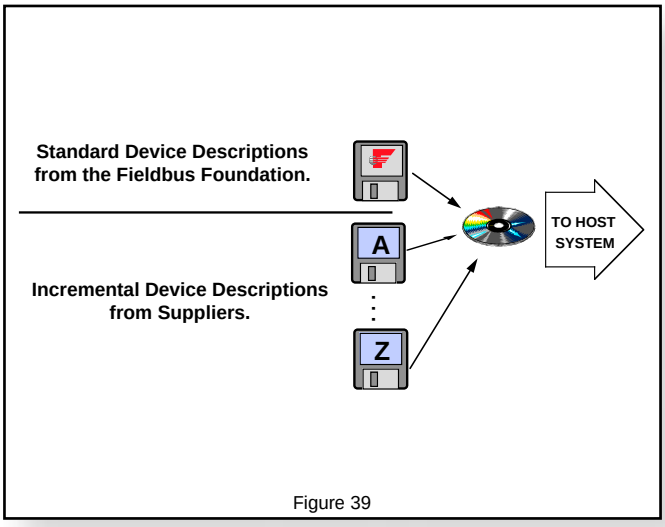

Figure 39

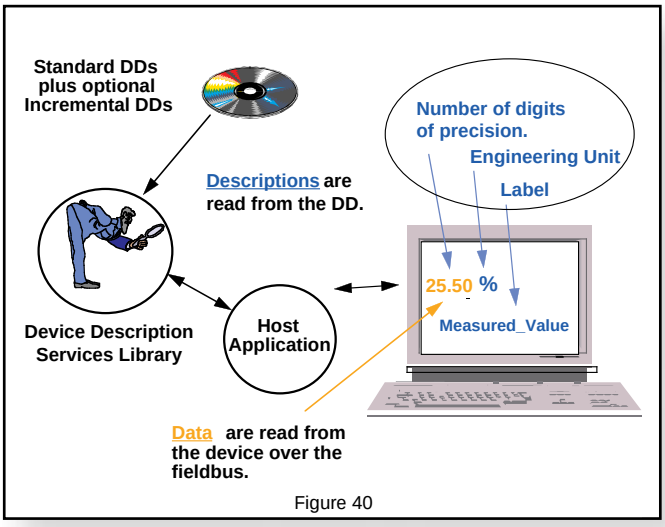

Figure 40

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New devices are added to the fieldbus by simply connecting the device to the fieldbus wire and providing the control system or host with the standard and incremental (if any) DD for the new device (Figure 41).

DDS technology allows operation of devices from different suppliers on the same fieldbus with only one version of the host human interface program.

3.5.3 Device Description Hierarchy

The Fieldbus Foundation has defined a hierarchy of Device Descriptions (DD) to make it easier to build devices and perform system configuration. The hierarchy is shown in Figure 42.

The first level in the hierarchy is the Universal Parameters. Universal Parameters consist of common attributes such as Tag, Revision, Mode, etc. All blocks must include the Universal Parameters.

The next level in the hierarchy is the Function Block Parameters. At this level, parameters are defined for the standard Function Blocks. Parameters for the standard Resource Block are also defined at this level.

The third level is called Transducer Block Parameters. At this level, parameters are defined for the standard Transducer Blocks. In some cases, the transducer block specification may add parameters to the standard Resource Block.
The Fieldbus Foundation has written the Device Descriptions for the first three layers of the hierarchy. These are the standard Fieldbus Foundation DDs.

The fourth level of the hierarchy is called Manufacturer Specific Parameters. At this level, each manufacturer is free to add additional parameters to the Function Block Parameters and Transducer Block Parameters. These new parameters will be included in the “incremental” DD discussed earlier.

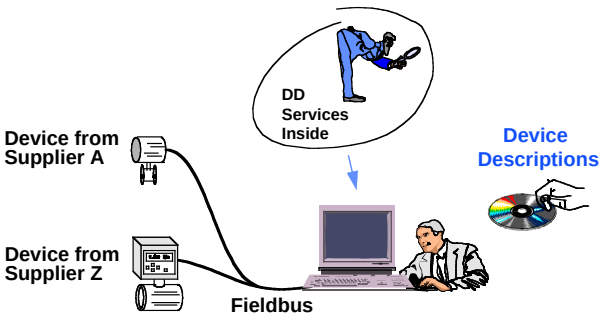

Figure 41

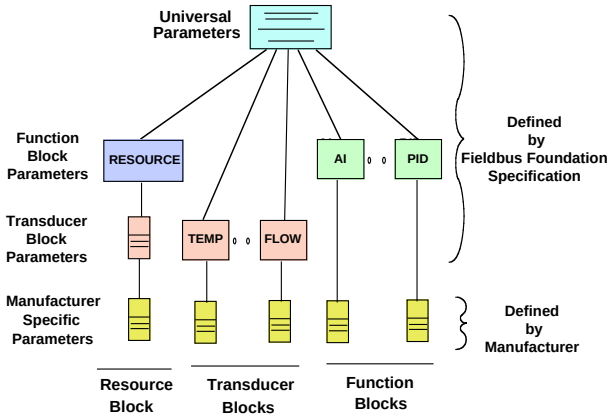

Figure 42

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3.5.4 Interoperability

FD-210 Interoperability Tester User's Guide

Each manufacturer will provide the Fieldbus Foundation with an interoperability test report for each device.

The test report identifies the Universal, Function Block, Transducer Block, and Manufacturer Specific Parameters in the device. An identifier called the Manufacturer's Identification is used to correlate the device type and revision with its Device Description and DD revision.

Any host using the Device Description Services (DDS) interpreter will be able to interoperate with all parameters that have been defined in the device by reading the device's DD.

4. SYSTEM CONFIGURATION

Fieldbus system configuration consists of two phases: 1) System Design and 2) Device Configuration.

4.1 System Design

The system design for fieldbus-based systems is very similar to today's Distributed Control Systems (DCS) design with the following differences.

The first difference is in the physical wiring due to the change from 4-20 mA analog point-to-point wiring to a digital bus wiring where many devices can be connected to one wire.

Each device on the fieldbus must have a unique physical device tag and a corresponding network address.

The second difference is the ability to distribute some of the control and input/output (I/O) sub system functions from the control system to the fieldbus devices. This may reduce the number of rack mounted controllers and remote mounted I/O equipment needed for the system design (Figure 43).

4.2 Device Configuration

After the system design is completed and the instruments have been selected, the device configuration is performed by connecting Function Block inputs and outputs together in each device as required by the control strategy (Figure 44).

After all of the function block connections and other configuration items such as device names, loop tags, and loop execution rate have been entered, the configuration device generates information for each fieldbus device.

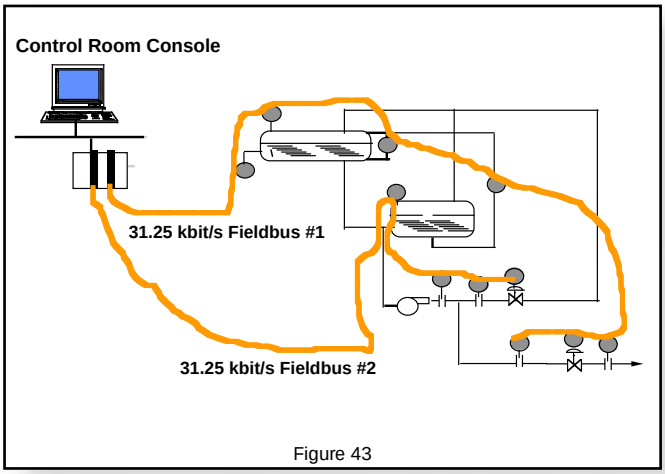

Figure 43

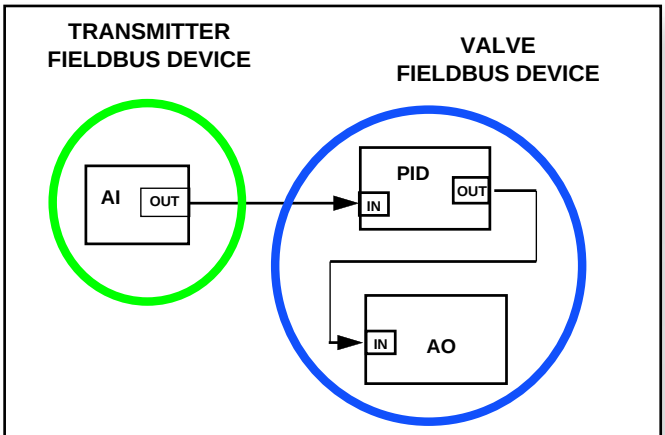

Figure 44

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A stand-alone loop can be configured if there is a field device that is a Link Master. This will allow continued operation of the loop without the configuration device or a central console (Figure 45).

The system becomes operational after the field-bus devices have received their configurations.

5. FIELD TEST SYSTEM

Benefits of fieldbus technology were directly observed during field tests on real processes. This section gives the results of one of the tests. Fieldbus devices were installed on a condensate recovery system in a utilities plant.

The recovery system receives the steam condensate returning to the utilities plant from the rest of the site and returns this condensate into the water treatment system (Figure 46).

The process consists of two tanks: a flash tank, which is approximately 85 gallons and a condensate tank of approximately 20 gallons. The flash tank is mounted directly above the other tank.

The returning condensate flows into the flash tank, where lowering of pressure may cause the condensate to flash to steam. The liquid condensate flows down into the condensate tank from which it is pumped forward into the boiler feedwater system.

5.1 Test Instrumentation

Fieldbus transmitter instrumentation installed on the system included:

- level on each tank and across both tanks
- pressure on the flash tank
- flow on the boiler feedwater system
- total pump flow
- recycle flow

The control valves were equipped with digital positioners which were used to control the boiler feedwater treatment and recycle flow.

The instruments were connected to one of two fieldbuses connected to a distributed control system (DCS) located in the utilities control room. The installation used a combination of existing twisted pair wiring and new wiring. While not required by the process, intrinsic safety barriers were demonstrated on the system.

Performance of the fieldbus was monitored by bus analyzers.

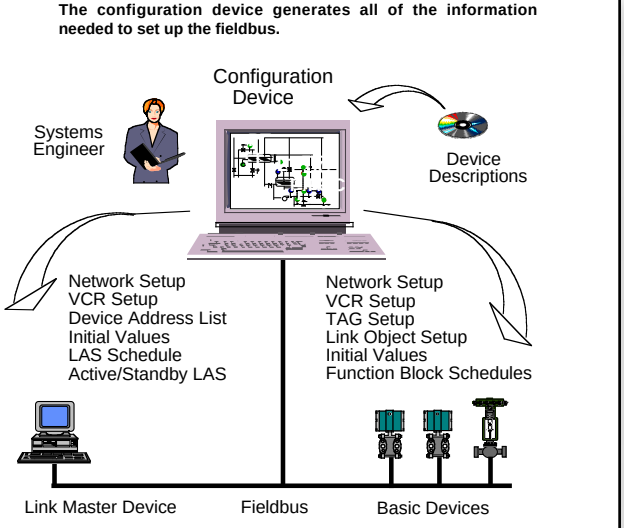

Figure 45

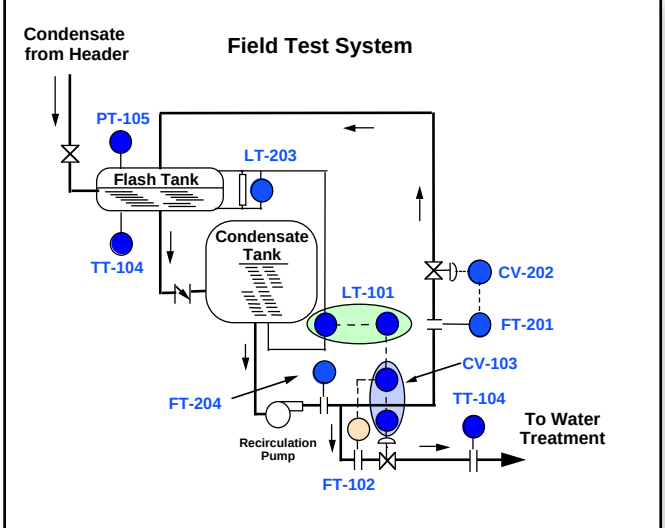

Figure 46

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Wiring was configured by connecting the fieldbus devices to one of two terminal panels in a junction box located by the process equipment. Two wire pairs, one pair for each terminal panel, were used to connect the fieldbuses to the control room.

The total condensate level of the system is controlled by selecting a preferred setpoint on the level PID, LIC-101, which is located in the level transmitter. The level PID is used as the primary loop cascaded to the flow PID, FIC-103, located in the valve on the feedwater system.

The re-circulation of condensate, from the condensate tank to the flash tank, is controlled by an additional PID loop, FIC-202, located in the valve. The control strategy for this cascade loop is totally implemented in the transmitters and flow valve as shown in Figure 47.

5.2 Installation, Startup, and Operation Benefits Observed

The wire runs, from fieldbus devices to the terminal panel, averaged 28 metres of new wire for each device, while two 185 metres of existing wire runs were used from each of the terminal panels to the control room.

If standard 4-20 mA analog devices had been used, ten new runs of 230 metres (28 metres from the device to the terminal panel plus 185 metres to the equipment room plus 17 metres to the DCS) would have been required. Savings in installation costs are summarized in the following table.

Wiring Technology	Wire Length	Number of Screw Terminations
4-20 mA Analog	2300 metres	120
Digital Fieldbus	510 metres	46
Savings with Fieldbus	1790 metres	74
Savings in %	78%	62%

The reduction of interface cards (by 50%), equipment cabinet space (caused by a reduction in the number of I/O interfaces), and the elimination of termination panels resulted in a 46% reduction in equipment costs.

Some applications might specify fewer devices per wire pair than the test system. In that case, the savings shown in the above table would be proportionately reduced according to the specific wiring configuration.

During the checkout phase, a reduction in effort to confirm the proper connection of the fieldbus devices was observed. One person performed the checkout by using the test tool connected to the fieldbus. With conventional 4-20 mA wiring, two people would have been required to check out each wire and confirm operation of each transmitter.

Each transmitter was interrogated and adjusted remotely. Device parameters such as the high and low range values were changed without having a technician adjust a potentiometer in the field.

When a device was disconnected from the fieldbus, the disconnection did not affect any other devices remaining on the bus. When the device was reconnected, the system had no trouble re-establishing communication with the device. Approximately two person-days of labor (25%) were saved due to the remote verification of wiring, remote device identification, and remote device configuration checkout.

The processing load on the DCS controller was reduced because of the PID algorithms which were executing in the fieldbus devices.

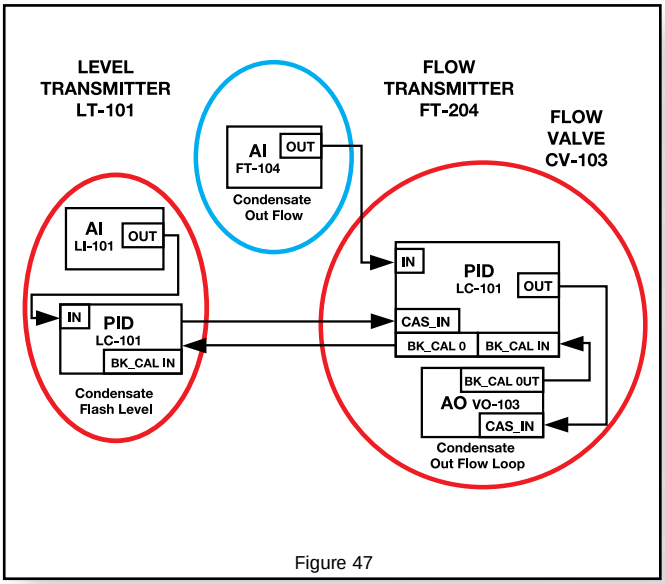

Figure 47

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6. HIGH SPEED ETHERNET

A **Linking Device** is used to interconnect 31.25 kbit/s fieldbuses and make them accessible to a High Speed Ethernet (HSE) backbone running at 100 Mbit/s or 1Gbit/s (Figure 48). The **I/O Subsystem Interface** shown in the figure allows other networks such as DeviceNet® and Profibus® to be mapped into standard FOUNDATION fieldbus function blocks. The I/O Subsystem Interface can be connected to the 31.25 kbit/s fieldbus or HSE.

Since all of the 31.25 kbit/s FOUNDATION fieldbus messages are communicated on the HSE using standard Ethernet protocols (e.g. TCP/IP, SNTP, SNMP, etc.), commercial off-the-shelf HSE equipment such as Switches and Routers are used to create larger networks (Figure 49). Of course all or part of the HSE network can be made redundant to achieve the level fault tolerance needed by the application.

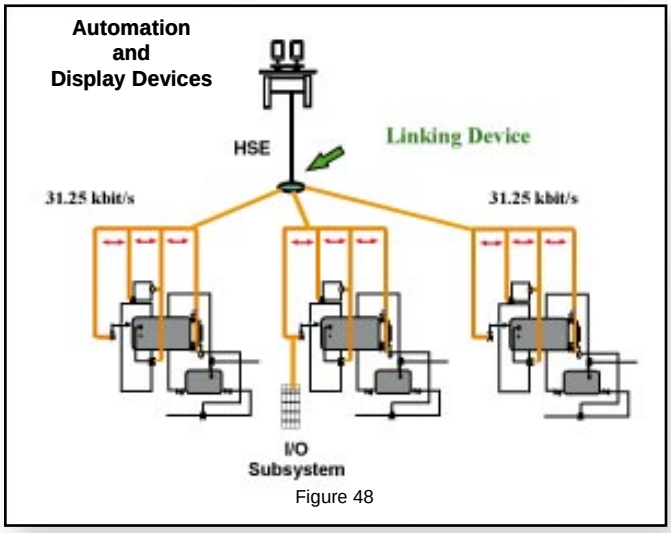

Figure 48

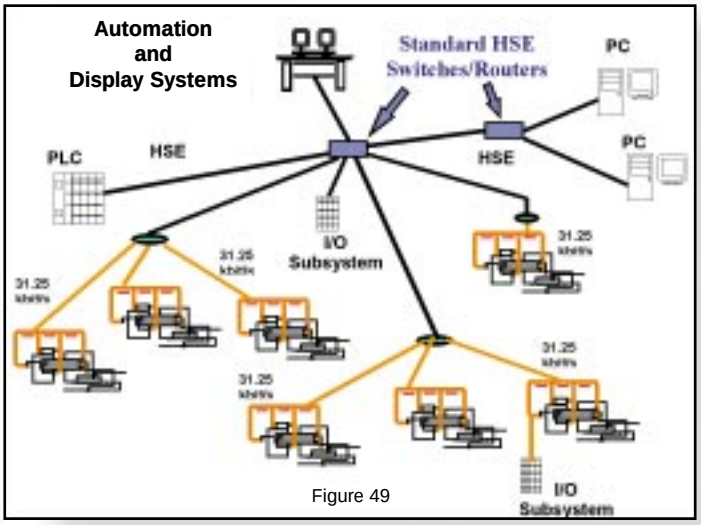

Figure 49

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7. REFERENCES

1. Fieldbus Standard for Use in Industrial Control Systems, Part 2: Physical Layer Specifications and Service Definition, ISA S50.02-1992.

2. International Standard for Use in Industrial Control Systems, Part 2: Physical Layer Specifications and Service Definition, IEC 61158-2 (1993).

3. Digital data communications for measurement and control -- Fieldbus for use in industrial control systems, Part 3: Data Link Service Definition and Part 4: Data Link Protocol Specification, 61158 DIS, IEC SC65C/WG6 - ISA SP50, 1994-1998.

4. FOUNDATION Fieldbus Specifications, Revision 1.3, Fieldbus Foundation, 1994-1998.

5. Benefits Observed During Field Trials Of An Interoperable Fieldbus, Kurt A. Zech, Fieldbus Foundation, Paper #94-504 -- ISA, 1994

6. Abstract Syntax Notation One (ASN.1) The Tutorial and Reference, Douglas Steedman, Technology Appraisals Ltd., 1993, ISBN 1 871802 06 7

8. DOCUMENT LIST

The following documents are available from the Fieldbus Foundation.

AG-140 31.25 kbit/s Wiring and Installation Guide
AG-163 31.25 kbit/s Intrinsically Safe Systems Application Guide
AG-165 Fieldbus Installation and Planning Guide
FF-800 System Architecture Specification
FF-801 Network Management Specification
FF-816 31.25 kbit/s Physical Layer Profile Specification
FF-818 31.25 kbit/s Fiber Optic Physical Layer Profile
FF-821 Data Link Layer Services Subset Specification
FF-822 Data Link Layer Protocol Specification
FF-880 System Management Specification
FF-870 Fieldbus Message Specification
FF-875 Fieldbus Access Sublayer Specification
FF-890 Function Blocks -- Part 1
FF-891 Function Blocks -- Part 2
FF-891 Function Blocks -- Part 3
FF-900 Device Description Language Specification
FF-940 31.25 kbit/s Communication Profile
FD-100 DDL Tokenizer User's Manual
FD-110 DDS User's Guide
FD-200 Conformance Tester User's Guide
FD-210 Interoperability Tester User's Guide

8. ACRONYM TABLE

ASN.1	Abstract Syntax Notation 1
CCITT	International Telegraph and Telephone Consultative Committee
CD	Compel Data
DC	Direct Current
DCS	Distributed Control System
DD	Device Description
DDL	Device Description Language
DDS	Device Description Services
DLL	Data Link Layer
EUC	End User Council
FAS	Fieldbus Access Sublayer
FB	Function Block
FF	Fieldbus Foundation
FMS	Fieldbus Message Specification
HSE	High Speed Ethernet
Gbit/s	Gigabits per second
IEC	International Electrotechnical Commission
I.S.	Intrinsically Safe
ISA	The International Society of Measurement and Control
ISO	International Organization of Standards
kbit/s	kilobits per second
kHz	kilohertz
LAN	Local Area Network
LAS	Link Active Scheduler
mA	Milliampere
Mbit/s	Megabits per second
NMIB	Network Management Information Database
OD	Object Dictionary
OSI	Open Systems Interconnect
PC	Personal Computer
PDU	Protocol Data Unit
PHY	Physical Layer
PID	Proportional, Integral, Derivative
PN	Probe Node
PT	Pass Token
SM	System Management
SMIB	System Management Information Base
SNMP	Simple Network Managemant Protocol
SNTP	Simple Network Time Protocol
TCP/IP	Transport Control Protocol/Internet Protocol
TD	Time Distribution
VFD	Virtual Field Device
VCR	Virtual Communication Relationship

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